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# **Integrated Unmanned Air-Ground Robotics System**

## **FINAL REPORT – VOLUME I SUMMARY**

Submitted By:

### **UAH Integrated Product Team 2001**



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**Contract DAAH01-98-0-R001-D.O. 105**

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## **ABSTRACT**

Early strike forces of the future military are envisioned as being lightly armored to enable a rapid deployment. The increased vulnerability and operational tempo of lightly armored forces evokes the need for beyond-line-of-sight reconnaissance capability under the control of the troops on the ground. The objective of this work is to explore and evaluate system level concepts that fulfill this mission using an unmanned air/ground vehicle. The study included requirement definition, concept synthesis, and down selection to three final configurations. The assumed time of deployment is the year 2025. Engineering students from the University of Alabama in Huntsville and Ecole Supérieure des Techniques Aéronautiques et de Construction Automobile participated on the teams. The students worked in three integrated product teams in a design competition. Team 1 developed a ducted fans/pulse detonation engine vehicle with semi-spherical wheels. Team 2 proposed a flapping wings concept driven by electric motors and powered by fuel cells. Ground mobility is provided by a tracked system. Team 3 offered an ion drive idea powered by advanced fuel cells. A review team consisting of government and industry professional ranked the final proposals and selected the Team 2 flapping wing concept as the best proposal. An overview of the requirements, design alternatives, and the final design is given in this report.

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## NOMENCLATURE

AHS	American Helicopter Society
AIAA	American Institute of Aeronautics and Astronautics
AMCOM	United States Army Aviation and Missile Command, Redstone Arsenal, Alabama
AMRDEC	Aviation and Missile Research, Development, and Engineering Center
BLOS	Beyond Line of Sight
CNN	Cable News Network
ECE	Electrical and Computer Engineering
ESTACA	Ecole Supérieure des Techniques Aéronautiques et de Construction Automobile
GPS	Global Position System
GRAD	Global Research and Development Incorporated
FLOT	Forward Line of Troops
IPT	Integrated Product Team
IVHM	Integrated vehicle health management
LOS	Line of Sight
LRU	Line Replacable Units
MAE	Mechanical and Aerospace Engineering
NASA	National Aeronautics and Space Administration
Op Tempo	Operational Tempo
PDE	Pulse Detonation Engine
PEM	Proton Exchange Membrane
RCM	Reciprocating Chemical Muscle
RSTA	Reconnaissance Surveillance and Target Acquisition
TF/TA	Terrain Following/Terrain Avoidance
UAGV	Unmanned Air/Ground Vehicle
UAH	The University of Alabama in Huntsville, Huntsville, Alabama
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
VROC	Vertical Rate of Climb
XTR-1	Team 1 Final Concept

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## **1.0 INTRODUCTION**

The U.S. Aviation and Missile Command, Advanced Systems Concepts Directorate (AMSAM-RD-AS) at Redstone Arsenal, Alabama funded this study with the University of Alabama in Huntsville, Huntsville, Alabama. The work was performed on Contract DAAH01-98-0-R001, Delivery Order 105. John C. Fulda and James P. Winkeler served as the AMCOM technical monitors for the project. Robert A. Frederick, Jr. acted as the UAH Principal Investigator. The period of performance was from August 8, 2000 to August 15, 2001. The final report is submitted in four volumes. Volume 1 summarizes the work performed on the project. The appendix material in Volume 1 contains the Concept Description Document, Baseline Presentation Charts, and Review Team Information. Volumes 2, 3, and 4 each describe the final concept developed by each integrated product teams. Appendix material in Volumes 2, 3 and 4 contain supporting calculations, White Papers, and team resumes.

### ***1.1 UAH IPT Project Background***

In high-technology business, companies are using multi-disciplinary teams to decrease product costs and reduce time to market. This approach demands that specialist from diverse backgrounds learn how to work interactively under a set of system-level requirements. Top companies must be able to put together products in conjunction with domestic and international business partners using advanced technologies in a dynamic political/economic environment.

The University of Alabama in Huntsville (UAH) has established an Integrated Product Team (IPT) project to better introduce students to this teamwork environment. The IPT project uses industrial mentors<sup>1,2</sup> to guide teams of engineering,<sup>3</sup> business,<sup>4</sup> and liberal arts<sup>5</sup> students in a competitive design project.<sup>6</sup> Past projects have included a hybrid rocket sub-orbital vehicle,<sup>7</sup> a tactical missile,<sup>8</sup> a maglev train, a rocket-launched glider, two advanced rotorcraft projects,<sup>9</sup> and a crew transport/recovery vehicle for the International Space Station.<sup>10</sup> Details of these projects can also be found at the [www.eb.uah.edu/ipt](http://www.eb.uah.edu/ipt) web page.

### ***1.2 UAGV Project Approach***

The UAGV project covered the period of one calendar year or three academic semesters. In the fall semester of 2000, a series of background lectures and meetings were held among the UAH team leaders and AMCOM customer representatives to develop a written Concept Description Document that detailed the requirements for the system. The background lectures were provided by government and industry personnel on topics related to the technical and programmatic aspects of the project.

In the spring 2001 semester, three IPTs were formed to complete the concept studies. Twenty-eight seniors from the UAH Department of Mechanical and Aerospace Engineering, twelve fourth-year students from ESTACA, an engineering college in France, and four students from the UAH Department of Electrical and Computer Engineering were distributed among the three integrated product teams. Other UAH students and instructors supported the project including a team from the Department of Industrial and Systems Engineering who studied the team development process, two teams in Administrative Sciences who developed technology marketing plans, and a group of Liberal Arts Students who worked on resume packages for the participants.

The concept study (spring 2001) is divided into three phases. In Phase 1, all three IPTs worked together to configure a Baseline Concept that attempted to fulfill the project requirements using existing technologies. During this phase an assessment of existing vehicles was also made to see how many of the requirements they could meet. This established the deficiencies of current technologies and gave the mentors a chance to interact with the students to instruct them in the design process. At the end of this Phase 1, one IPT briefed a Review Team consisting of government and industry professionals. The students presented the Baseline Concept, an assessment of current vehicles, and recommendations for revisions to the Concept Description Document. The Baseline Review Charts are contained in Appendix B.

For Phase 2, the three student IPTs worked independently and each team produced alternative configurations to the Baseline Concept. They could include technologies envisioned possible for deployment by the year 2025. The teams each synthesized three very different configurations to look at a wide range of possible technologies. At the end of this Phase 2, each IPT produced a White Paper and made a private poster presentation to the Review Team. They presented a description of each concept and an evaluation matrix that showed their assessment of each configuration's attributes relative to the Concept Description Document. Each team used this assessment and feedback from the Review Team to select one of their concepts for refinement in Phase 3.

In Phase 3, each team refined their selected concept. This involved making estimates of weight, range, and operating characteristics of their system. It included developing technology roadmaps for the new technologies that would be required to implement the concept. They developed an outline of programmatic information including a development schedule, project costs, and project production. This information is documented by each IPT in a 50-page Final Proposal (Volumes 2, 3, and four of this Final Report).

At the end of Phase 3, each IPT made a 20-minute presentation to the Review Team. The Review Team then asked questions based on the Final Proposal and the oral presentation. Each reviewer ranked the teams based on criteria adapted from the AIAA Design Competitions (review criteria are shown in Appendix C). The Review Team Chairman then compiled the results and made the ranking. Five members of the top-ranked IPT were then invited to present their work at a symposium in France. The UAH Student Government Association funded the international travel.

During the summer semester of 2001, the Principal Investigator and a small follow up team completed reporting activities and did further investigations on a propulsion concept.

## **2.0 PROJECT REQUIREMENTS**

### ***2.1 The Needs***

An increased operational tempo is imperative for future forces. As conflicts arise in many different countries, we must be prepared to rapidly move troops and supplies to any location in the world. The op tempo predicted for the next war is 50-100 km/h. This pace is significantly greater than that of World War II and requires vehicles that can move and negotiate terrain at greater speeds. At the battalion level, these medium and light forces will need increased situational awareness to enhance their survivability and increase their effectiveness.

An increase in robotics is essential for the future Army. Due to a reduction in forces, fewer troops are available for service. Additionally, worldwide conflicts require these troops to be able to deploy rapidly to the point of interest. This ability to deploy quickly comes at a price to the soldier. No longer will heavy armor and the supplies that keep a soldier's vulnerability low accompany him. Robotics can augment the power of the troops by performing multiple missions without the risk to human life. The need for robotics exists to fill the gap for "dirty, dangerous, and dull" missions. The use of robotics may even eliminate the need for human forces to perform dangerous missions.

The military wants to prevent casualties whenever possible. The "CNN factor," meaning the extensive, publicly followed media coverage, demands a "clean" war for Americans. Reconnaissance missions performed by soldiers on the FLOT are extremely dangerous, and are impossible BLOS. By performing these missions successfully and enhancing the reconnaissance, surveillance, and target acquisition (RSTA) capability of their respective battalions, an autonomous-robotic craft that will function at the forward line of troops (FLOT) and beyond the line of sight (BLOS) would allow the FLOT to make more informed, and thus, better decisions and thereby reduce casualties.

## ***2.2 The Requirements***

The United States Army Aviation and Missile Command (AMCOM) developed a set of notional specifications for a future vehicle that integrates the capabilities of both a UAV and a UGV to perform missions normally performed by soldiers in the field. The detailed Concept Description Document that served as the guidelines for this project is shown in Appendix A.

The requirements for this type of operational capability exist on three different levels. At the first level, the UAGV must satisfy the Army's objectives. This need calls for an intelligent, autonomous vehicle that is capable of performing a task. Therefore, the vehicle must be survivable, must be capable of maintaining the operational tempo, and must increase the reconnaissance, surveillance and target acquisition (RSTA) abilities on the battlefield.

On the second level, the vehicle must meet the mission/payload requirements. This involves the vehicle being able to fly to the objective area in 30 minutes in a nap of the earth flight configuration while avoiding both obstacles and potential enemies. Upon reaching the deployment site, it must be able to either hover for 60 minutes or land on the ground and move itself, via ground propulsion, to the designated area. When the mission is complete, the UAV/UGV must then be able to return to its launch area.

Finally, the third level involves specific vehicle requirements. The vehicle requirements are the actual performance parameters that the UAGV must meet to perform the mission. These involve the vehicle being able to fly at a minimum of 30 km/hour, with a 250 ft/min VROC at a maximum altitude of 4000 ft. An example of how these levels fit in with each other is now illustrated. The vehicle requirement of being able to have a vertical rate of climb of 250 ft/min enables the UAV/UGV to meet the mission requirement of being able to fly in a nap of the earth configuration. Flying using this profile enables the UAGV to avoid detection and therefore become more survivable.

Table 1 summarizes the key features of the detailed Concept Description Document found in “Appendix A – Concept Description Document.”

Table 1. UAGV Concept Description Document Summary

<b>CDD Requirement</b>	<b>Requirement</b>
Range from launch point	15 km
Cruise Speed	30 km/hr
VROC	250 ft/min
VTOL Capability	Yes
Payload:	60 lb
Operational Altitude	0 to 500 ft AGL
Hover to full flight profile	Yes
Operation	Autonomous or Semi-autonomous
Acoustic Signature	Near Quiet
Communications	BLOS
Deployment	2025

There are technical and system-integration challenges to overcome to produce this system. The technology needed to have a truly “intelligent” system that can monitor, think and actually react to a situation is one of the largest challenges to meet. Artificial intelligence has come a long way, but is still in its infancy. Many communication methods still require the vehicle to be in the line of sight of the monitoring vehicle or the use of an orbiting satellite in order to send telemetry. Tying in the capabilities of a system that can operate in both the air and the ground undoubtedly brings challenges to reduce the weight. Current propulsion methods are bulky and involve high specific fuel consumption. Cutting the weight down with lighter and stronger materials and coupling it with high efficiency engines is the challenge of today and the future for this system.

### **3.0 THE BASELINE CONCEPT**

The Baseline Concept established the limitations of existing technologies in meeting the project requirements.

Figure 1 is an artist rendering of the “Pawnee.” The vehicle uses 13-foot diameter counter-rotating blades for lift and forward air propulsion. A 100-hp, 4-cylinder, supercharged engine provides power. Four rubber wheels each provide ground propulsion driven independently by electric motors. The vehicle has a titanium alloy frame and a carbon fiber composite skin material. The estimated weight of the Pawnee is 614 pounds. GPS and inertial sensors provide guidance and the system only has semi-autonomous control. Estimated performance included a VROC of 250, a range of 15 km, and a maximum air speed of 30 km/hr.

Because the guidelines for the baseline specified the use of existing technology, the Pawnee could not meet some of the key project requirements. The vehicle had difficulty meeting the requirements of near-quiet acoustic signature and could not meet the requirements for autonomous operation.

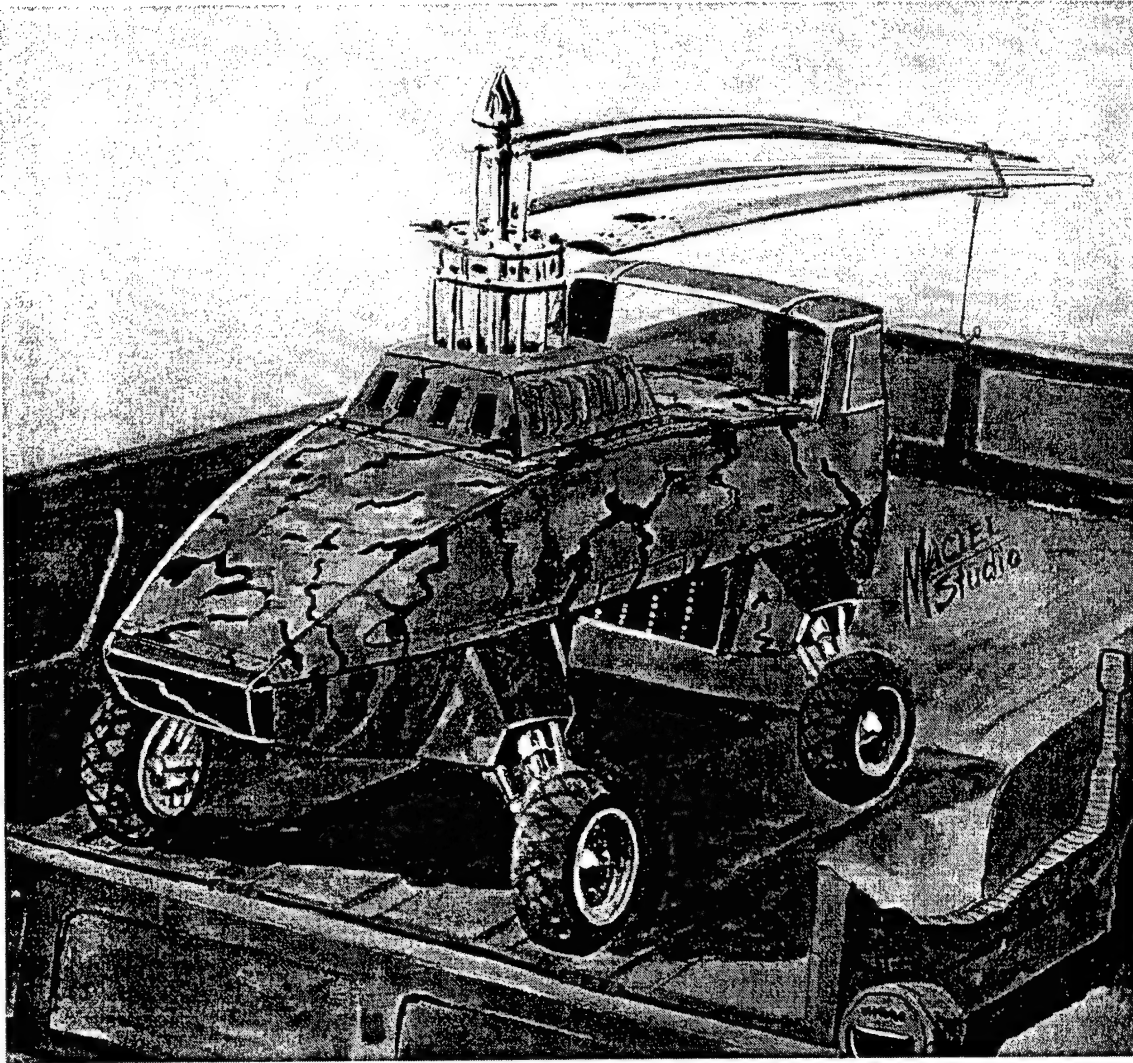


Figure 1. Baseline Configuration, The "Pawnee"

#### **4.0 THE ALTERNATIVE CONCEPTS**

Figure 2 shows the alternative concepts that each team synthesized following the baseline design. This section of the paper will give a summary of the basic air and ground propulsion aspects of each design and the overall rationale of each team's selection of a preferred configuration. Detailed descriptions of the alternative concepts are found in the Appendix materials of Volumes 2, 3, and 4 of this Final Report.

##### ***4.1 Team 1 Alternative Concepts***

Design 1A (CD1-1) is a vehicle that uses one ducted fan and four wheels. This concept has one ducted fan powered by a Wankel engine to provide vertical lift. Thrust control is accomplished using four thrust-vectoring ports. A pulse detonation engine will provide the forward flight movement of the vehicle. This design will have four wheels using a suspension system that will

allow the vehicle to move over rugged terrain. The vehicle will fit within the constraints of a Hum-Vee trailer and will weigh approximately 350 pounds.

Design 1B (CD1-2) is an electrically powered vehicle with a single, centrally located ducted fan to provide lift. It combines existing aerospace propulsion systems with electricity from fuel cells to provide a hover to full flight profile. In addition to the large ducted fan the vehicle will have 4 small fans to provide directional control and stability for the system. This vehicle will be lighter than the Baseline Concept. The vehicle has four wheels with movable struts. The frame and skin of the vehicle will be made out of carbon fiber. It will weigh approximately 550 pounds.

Design 1C (CD1-3) will have three magnetic levitation devices, which use magnetic fields to make an object repel another object. It is a vehicle that uses magnetic levitation device and ion thrust. It uses tracks as its means for mobility on the ground. The ion drive propulsion system will be scaled down to provide the proper amount of thrust. The ground mobility package will consist of two tracks located underneath the vehicle. The body and frame will be made of aluminum, because of its low magnetic properties. This will prevent interference with the magnetic levitation device. It will weigh approximately 300 pounds.

Team 1 selected Concept 1A after careful evaluation of all four designs. Overall, the concept was better than the other three even though it lacked in the cost, risk, and schedule of the vehicle factors. This design has some very attractive features such as a lightweight propulsion unit in the pulse detonation engine. Originally the team was going to choose CD1-3 but after researching the magnetic levitation device and the ion drive system it was found that not enough information existed to produce a viable concept. CD1-1 was also chosen because of the forward thinking of the pulse detonation engine and the high efficiency of the ducted fans. These features made the first concept very attractive to the team.

#### ***4.2 Team 2 Alternative Concepts***

Design 2A, the Blowfish, is a lighter than air vehicle. An inflatable balloon filled with helium will provide lift. Small ducted fans driven by electric motors allow to pitch and yaw; assist in the vertical takeoff and landing so less helium is required. Fuel cells provide electrical power. A hovercraft system driven by an electric fan is used for ground navigation. The hovercraft will be able to traverse water and marsh as well as land. The two side fans will control the forward movement while it is on the ground. The vehicle will feature navigation, sensors, and communications equipment similar to the baseline design.

Design 2B, the Choctaw, is a modified autogyro. For vertical takeoff, a rotor on top of the vehicle is run to a specified angular velocity range and at the instant of takeoff, power to the rotor is disconnected to eliminate any torque problems during flight. A propeller on the rear of the vehicle provides forward motion through the air. This forward movement causes air to pass over the rotor blades on the top of the vehicle which then rotate and produce lift. While on the ground, the system is carried on miniature tracks similar to those on a tank. A small caster wheel in the front of the vehicle will turn freely. The visual sensor will be a panoramic camera with a 360° view of the battlefield. The communications and navigation systems will be similar to the baseline design.

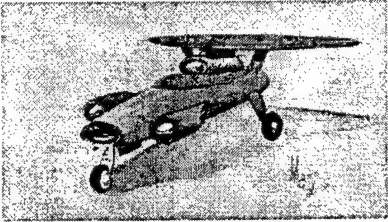
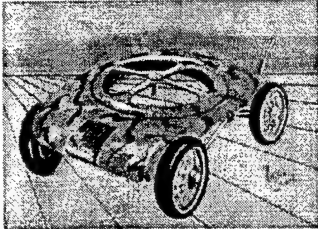
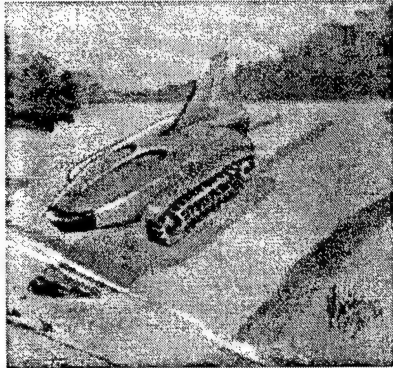
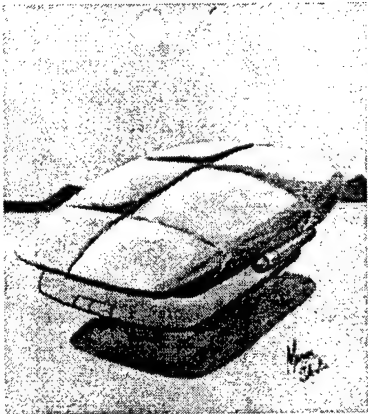
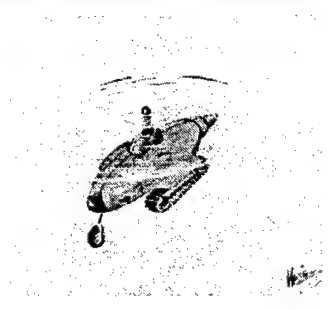
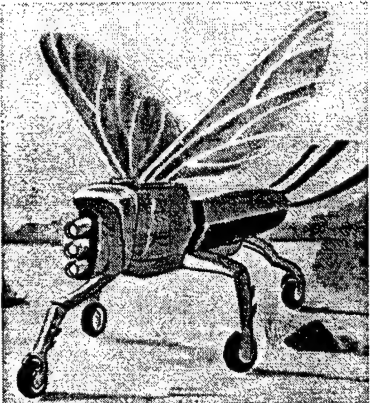
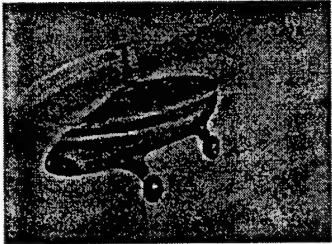

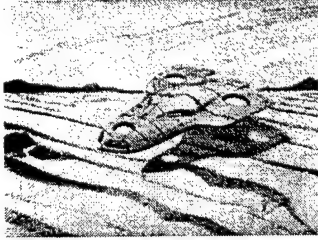
IPT 2001 ALTERNATIVE CONCEPTS – PHASE 2			
T E A M  1			
	Concept 1A - CD1-1	Concept 1B - CD1-2	Concept 1C - CD1-3
			
T E A M  2	Concept 2A - Blowfish	Concept 2B - Choctaw	Concept 2C - <u>Oiseau</u>
			
	Concept 3A – Rotor Racer	Concept 3B – The Moth	Concept 3C – Ionic Defender

Figure 2. Alternative Concepts

Design 2C is the flapping wings concept called the Oiseau. The design uses flapping wings and a reciprocating chemical muscle (RCM)<sup>11</sup> generates the power for flapping. The RCM is a regenerative device that converts chemical energy into motion through a direct chemical reaction. There is no combustion-taking place nor is there an ignition system required. The RCM is not only capable of producing autonomic wing flapping, but also small amounts of electricity for control of sensors and other electrical components.

According to the results of the Team 3 evaluation, the Oiseau scored highest overall. The Oiseau meets all of the primary requirements, and scored equal or higher than the other concepts in important categories, such as ability to meet cruise speed, ability to meet VROC requirement, and ability to execute the flight profile. In addition, the Oiseau ranks highest in survivability due to its bird-like appearance and its exceptional flight agility. The Oiseau has the most potential for development, as well as the most potential to perform the tasks required while keeping the gross weight of the vehicle to a minimum.

#### ***4.3 Team 3 Alternative Concepts***

Concept 3A, the Rotor Racer, is similar to the baseline, is comprised of a rotorcraft configuration. The design also utilizes a Wankel rotary engine and retractable wheels. Even though this design is similar to the baseline, it weighs approximately two hundred pounds less. The Racer has co-axial, counter-rotating rotors that are made of strong, lightweight materials. The aircraft is built on a monocoque structure that reduces the weight and increases the survivability.

Concept 3B, The Moth, is based on a blended wing body similar to that of the U.S. Air Force B-2 Bomber. This design incorporates two ducted fans for VTOL that pivot along the wing axes to provide forward thrust. No ground robotics were included in this design due to the ability of the ducted fans to provide enough maneuverability for "near earth" configuration. A fuel cell is used as a power source for this system.

Concept 3C, the Ionic Defender, is designed with the purpose of maintaining a low radar cross-section and near quiet acoustic signature. The Ionic Defender utilizes ion propulsion for vertical and horizontal flight. The electricity is provided by high capacity fuel cells. The ion engines will be used for hover for near ground activities and for VTOL. Also there will be separate ion engines for horizontal propulsion. The lifting body design will reduce the need for the vertical ion engines during horizontal flight.

Although the Ionic Defender is unconventional, it proves to be the most innovative design that is able to meet most, and exceed many of the requirements set forth by the specifications. Based on its near quiet operation, low power consumption, and stealth-like mobility, Team 3 selected the Ionic Defender as its preferred concept.

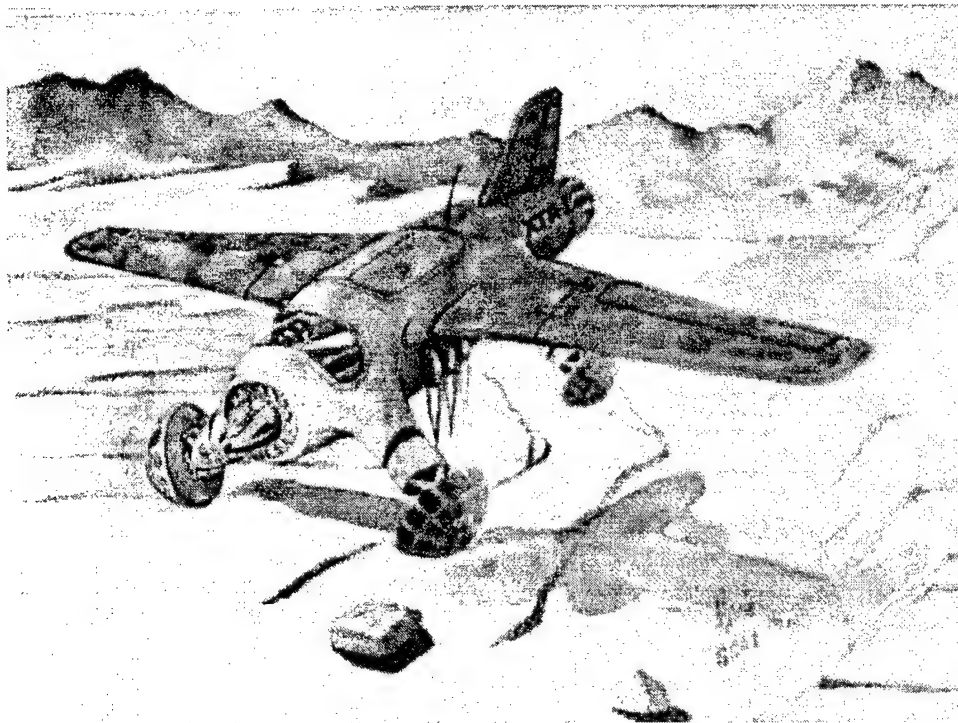
## **5.0 THE FINAL PROPOSALS**

### ***5.1 Team 1 Solution–The XTR-1***

Extreme Engineering designed the XTR-1, illustrated in Figure 3, a UAGV that will meet most of the customer requirements. The XTR-1 will have an elliptical shape to prevent excessive drag on the vehicle. XTR-1's major systems are the engines, ducted fan, and wheels. The vehicle is lightweight, coming in at around 480 pounds. In addition, the XTR-1 is capable of VTOL and has a VROC of 250 feet per minute. The vehicle can fly at 30 kilometers per hour during forward flight. The complete Team 1 proposal is Volume 2 of this Final Report,

Air propulsion is provided by two systems. Twelve thrust vectoring ports, six on either side, provide the VTOL. During forward flight these ports provide directional control for the vehicle. The thrust required for forward flight will be provided by the PDE. The PDE is very small dimensionally and is very lightweight. However even though it is small it provides a great deal of power. The XTR-1 has wings and a tail fin to provide extra lift and stability. The extra lift reduces the amount of power the engines must provide.

The XTR-1 has high ground mobility by utilizing semi spherical wheels on movable struts. These wheels are powered by the Wankel engine and are front wheel drive. The wheels are made from Abs plastic, which is a strong lightweight material. The struts are made from an aluminum-beryllium composite. This material is very strong and can be cast into many shapes.



**Figure 3. Team 1 Solution – The XTR-1**

The XTR-1 has a complete sensor package allowing the vehicle to operate without the payload. The vehicle will utilize radar, acoustic sensing, TF/TA, and communications platforms. The sensors will allow the XTR-1 to operate in adverse weather conditions such as fog or smoke. The communications will allow the vehicle to be capable of LOS and BLOS communications. The primary BLOS communication will be a high-frequency band. The vehicle will be semi-autonomous because some human interface will be required.

The pulse detonation engine or PDE is a simple concept with a simple design. The base concept behind the PDE is a detonation of a fuel air mixture, instead of deflagration that conventional jet engines use. With a detonation, a higher pressure is achieved; which translates in to greater thrust. Since the same amount or less fuel is used to achieve greater thrust, the efficiency is a good deal higher than that of even ramjets. The PDE has a theoretical ISP efficiency of 20-30% higher than ramjet technology.<sup>12</sup> In addition to greater efficiency, the unit is also lighter than its conventional counterparts, which endears it self to this concept. The actual machine workings are slightly more complicated. However, it is still far less involved than the standard jet engine.

The control and sensor equipment must be operated completely by computer to achieve the small timing tolerances. The injectors must be time coordinated with the exit of the detonation wave from the detonation chamber, and the predetonation. This also means that only high-performance injectors and ignition equipment can be used. The sensory equipment is the key to the precision control system. The constant monitoring of the PDE's performance allows for nearly instantaneous corrections.

The weight of the propulsion system is another major factor in the weight of the vehicle. The overall weight of the system, which includes the PDE and the Wankel engine, is 125 pounds. This is one of the major sources of weight for the XTR-1. Extreme Engineering is hopeful that the weight of the propulsion system will significantly decrease by 2025, however the vehicle will still work even if this does not occur. Table 2 shows a breakdown of the weight from each of the propulsion components.

Table 2. Propulsion Weight

Weight	
Wankel Engine	20.0 kg
JP-8 for Wankel	11.8 kg
JP-8 for PDE	13.7 kg
Battery	4.5 kg
PDE Engine	6.8 kg

The Wankel Rotary engine is a low-weight, high-efficiency internal combustion engine. The purpose of the Wankel in the selected design is to provide the vertical lift upon takeoff, landing, and hovering. The Wankel will run on JP-8 fuel, which is readily available today for military use. Figure 4 shows a schematic of the Wankel engine.

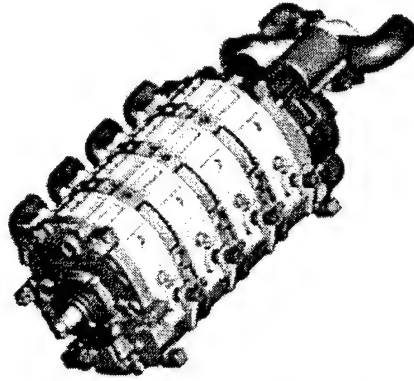


Figure 4. Wankel Engine

The pulse detonation engine (PDE) is being evaluated and developed as a potentially high-payoff new aeronautical propulsion system. The PDE represents a potential propulsion technology leap beyond the gas turbine engine.

Based on the results of several studies to date, the air-breathing PDE offers potential performance and life cycle cost payoff for both subsonic and supersonic vehicle applications. Potential applications of interest are propulsion systems for tactical aircraft (manned or unmanned), missiles and subsonic/supersonic propulsion source for future hypersonic aircraft.

In PDE, core jet engine components such as fans, compressors, and turbines are not required. This will decrease engine weights and increase engine reliability. Moreover, PDE technology maximizes the distance a plane can travel on a given amount of fuel. The time required for detonation development has been measured as a function of fuel type, equivalence ratio, initial pressure, diluents type, and diluents concentration.

It has been estimated that in order for the PDE cycle to be competitive with conventional turbojet/turbo ramjet systems, they will be required to operate in the 75 to 100 Hz range with near stoichiometric fuel/air mixtures. This represents a cycle time of approximately 10 msec, requiring a propellant refill time in the 5 msec range. Developing compatible air induction systems that will satisfy the above requirements, as well as provide adequate sealing from the high pressure- high temperature exhaust products, represents a major technology challenge.

Until actual PDE are on test stands, calculated performance numbers are only estimates. However, in an effort to address realistic performance, the fill valve coefficients have been estimated at 80% and realistic component efficiencies have been used. The airflow is injected through choked flow rotary valves into the combustion chamber.

Frequencies in the 70-100 Hz range are also assumed to be possible (an engine design study estimates that these frequencies are possible, but at a upper end of possible frequencies for annular designs) PDE thrust is a direct function of engine volume and operational frequency.

A shock trap boundary-layer bleed system is used to help stabilize the terminal shock train. A major feature of the diffuser is a center body, which allows a conservative area distribution, and

acceptable flow angles. The diffuser also includes a plenum aft of the center body, just forward of the engine face, to dampen engine-induced pressure waves.

The detonation chamber is a cylindrical tube about 9 cm. long and 6 cm. in diameter. Attached to this tube is an injector and a pre-detonation cylinder. The injector is equipped with an atomizer so the JP-8 fuel is more easily detonated. The predetonation cylinder is a smaller cylinder where the ignition of a small amount of fuel and oxidizer is preformed. In this smaller tube the fuel/oxidizer is in a state of deflagration which is converted to detonation. The resulting detonation wave enters the detonation chamber which in turn detonates the fuel/air mixture. The predetonation cylinder is used for two distinct reasons, that both mean higher pressure. Less fuel/oxidizer, which burns hotter, can be used, and the pressure needed for the deflagration to detonation transition is easier to obtain in the smaller tube. The ignition in the predetonation cylinder is started by an electrical spark. These operations are done at 100Hz. For this reason precision timing is critical. Figure 5 shows a generic diagram of a PDE engine.<sup>13</sup>

While the exact numbers of the latest prototypes are not available, some things are known. For instance, the Navy has been working to run PDE's of heavier fuels.<sup>14</sup> In addition, higher pressures have been achieved in many tests. Based on pressures seen in these tests the thrust can be calculated at 50% greater than the model.<sup>15</sup> From the base model several advancements are expected. The use of JP-8 fuel is expected to become a standard practice in the Navy. Fuel efficiency will most likely improve with experience, as most developing systems do. In addition, the relatively low weight of 30.2 lbs has the potential to reduce as much as 5 or 6 lbs. Lastly the aforementioned increase in pressure will yield greater thrust. For all these reasons, the pulse detonation is a prime choice for this design.

Detonation in the PDE is a form of combustion that differs significantly from deflagration, the type of combustion found in conventional gas turbine engines, pulse jets, and rockets. Deflagration is characterized by subsonic wave speeds, whereas the detonation combustion process occurs at high supersonic wave speeds relative to the unburned reactants (approximating Chapman-Jouquet C-J conditions). The detonation acts as an aerodynamic piston as it travels through the reactants gas mixture, raising the useable pressure by a factor of 7 to 8. This constant volume combustion process is thermodynamically more efficient than the constant pressure deflagration combustion process and provides greater available energy for performing useful work.

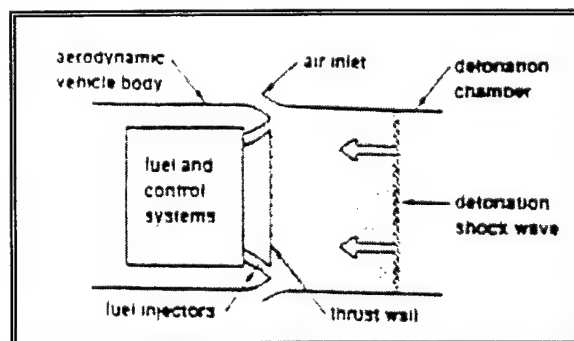


Figure 5. PDE Schematic

### 5.2 Team 2 Solution – The Oiseau

The Oiseau, a French word meaning bird, is a UAGV capable of meeting the future needs of US military forces. Utilizing an efficient design and mating together both technology and simplicity, the Oiseau meets the need of providing direct intelligence to support during dirty, dangerous, and dull missions. Figure 6 shows an artist rendering of the Oiseau.

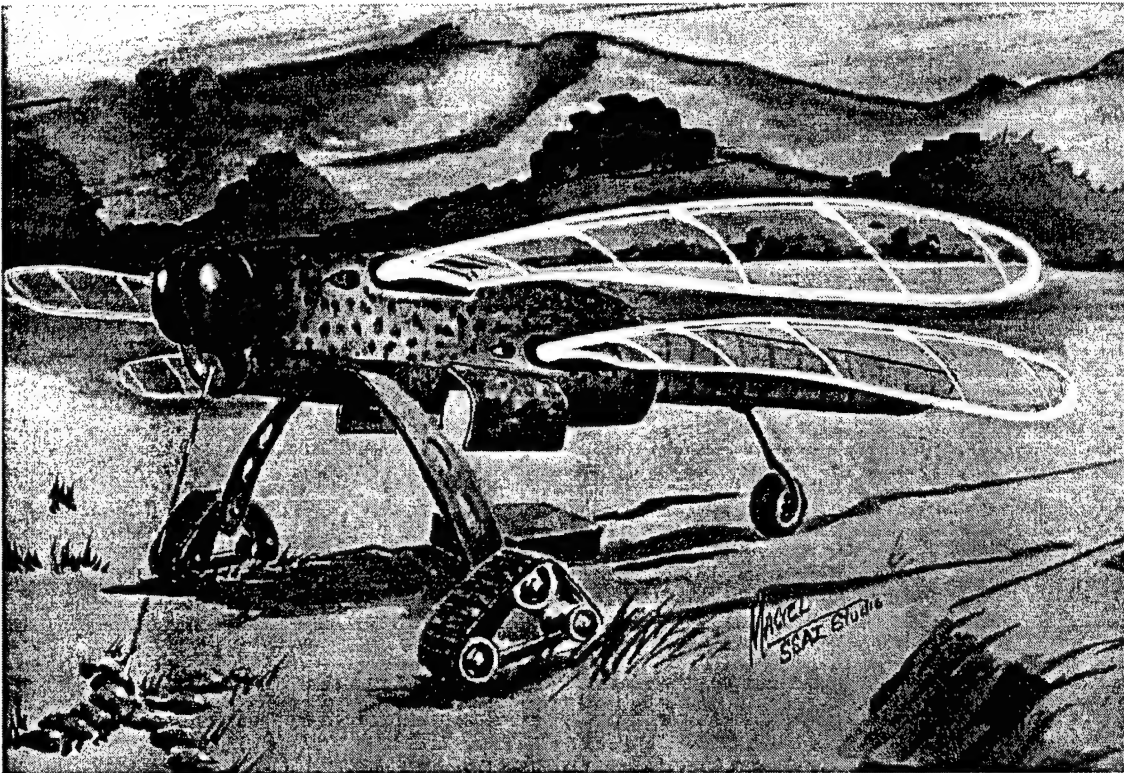


Figure 6. Team 2 Solution – The Oiseau

Forward intelligence support is the essence of the Oiseau's capabilities. Using a Fuel Cell system, the Oiseau is able to fly without the noise associated with most motors. As it produces power for the four flapping wings, it also produces the electricity needed to power the on-board navigational, surveillance and communication equipment. With only water as a by-product, it is also an environmentally sound energy production system. The "intelligent" sensor and communication package allows constant beyond line of site (BLOS) communication to the soldiers viewing, in real-time, what the sensors on the Oiseau see. The flapping wing configuration allows the Oiseau to fly with agility only matched by real birds and flying insects. On the ground, most any terrain can be traversed with a tracked system, configurable by the soldiers for wet, dry or slippery conditions, that is able to move at 5 mph. Both on the ground and in flight, an active camouflage system makes this near silent vehicle almost invisible to the naked eye as it blends in with its surroundings. Damage to the internal components, outer shell or wings of the Oiseau are easily replaced because all of these components are modular and thus easily removed and replaced/repared.

The capabilities of this UAGV are what make this vehicle stand alone as the future of intelligent robots for military use. Each component on its own is noteworthy, but the compilation of them in one system makes the Oiseau extraordinary. A couple of the most noteworthy components are first, the propulsion system. Because fuel cell systems are becoming more efficient and provide quiet power, they were the logical choice for a system that needs a near silent acoustic signature. It produces power without combustion, which keeps the thermal signature low, and runs on a minimal amount of fuel. It is coupled with the next noteworthy component; the extremely lightweight wings made with titanium and Gore-Tex. These wings can be actively twisted and bent using piezoelectric materials along the wing's edge and allowing the flight characteristics of the wing to change instantly.

The propulsion system of Oiseau is divided into three main parts: the energy's production, the motor and the transmission of the power to the wings. The energy is provided by a fuel cell, using hydrogen as fuel. The electricity produced can be used either for the electrical motor generating the flapping motion, or for the ground robotic system. Then the transmission system converts the spinning movement into an "up-and-down" motion.

In order to design a relevant propulsion system, we focused, during our research, on several requirements that it should fulfill. First, the Oiseau has to be as noiseless as possible, and second, the energy used has to be readily available in 25 years. These are the reasons why we decided to use an electric motor. With this choice made, the challenge was to find a source of electricity neither too heavy nor too big. Traditional batteries are not convenient because the power needed would require many batteries. Such a solution would have been too big, in terms of volume, and also too heavy. Considering all the research and progress done during the past few years, fuel cells appear very promising and they will overcome these problems. Furthermore, and that was part of our requirements, this technology is now under development. Several private companies invest money in this research. Many automotive manufacturers are racing to be the first to bring a fuel cell vehicle to the marketplace. Automakers and component suppliers are spending billions of dollars to drive fuel cell technology toward commercialization. We can reasonably expect that in 20 years, these technologies will be mature.

In principle, a fuel cell operates like a battery. Unlike a battery, a fuel cell does not run down or require recharging. It will produce energy in the form of electricity and heat as long as fuel is supplied. A fuel cell consists of two electrodes sandwiched around an electrolyte. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water and heat <sup>16</sup> Figure 7 shows a diagram of how the fuel cell works.

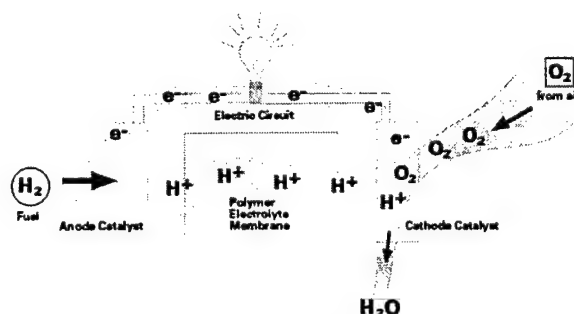


Figure 7. Fuel Cell

Hydrogen fuel is fed into the "anode" of the fuel cell. Oxygen (or air) enters the fuel cell through the cathode. Encouraged by a catalyst, the hydrogen atom splits into a proton and an electron, which take different paths to the cathode. The proton passes through the electrolyte. The electrons create a separate current that can be utilized before they return to the cathode, to be reunited with the hydrogen and oxygen in a molecule of water. This is shown in Figure 8.

A fuel cell system, which includes a fuel reformer, can utilize the hydrogen from any hydrocarbon fuel - from natural gas to methanol, and even gasoline. Since the fuel cell relies on chemistry and not combustion, emissions from this type of a system would still be much smaller than emissions from the cleanest fuel combustion processes.

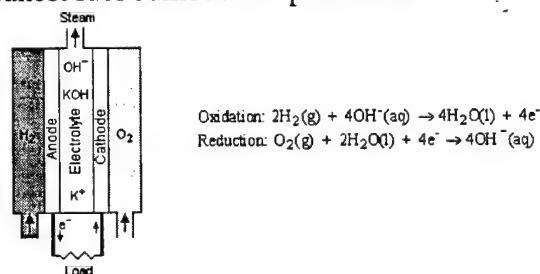


Figure 8. Combustion Process

Not only do they produce reasonable efficiencies in 30 kW sizes; they will likely be able to run quietly, need infrequent maintenance, emit little pollution and have high efficiency even at part load conditions.

Electricity is used by many of our modern high technology devices. Presently, batteries are used in these devices. Batteries do not have a long enough life for these applications. Fuel cells could provide continuous power for these devices. Every week or month a new supply of liquid fuel would be injected into the fuel cell.

Fuel cells are being proposed to replace Otto or Diesel engines because they could be reliable, simple, quieter, less polluting, and have even greater economy. Fuel cells are ideal for electric power production because electricity is both the initial and final form of energy that is produced.

Fuel cells are still a few years away from commercialization on a large scale because there are still some problems to be solved. However, if these problems are addressed, fuel cells will become predominate propulsion method in the future. In the last year there has been considerable progress made in this direction.

Now, thanks to the progress done, fuel cells reach characteristics of weight and compactness compatible with our requirements:  $1\text{kg/kW}$  and  $1\text{dm}^3/\text{kW}$ .<sup>17</sup> Considering the power required by the motor, which is 34.5, kW, the fuel cell needed for Oiseau will weigh 35 kg (67 lbs.) and its volume is  $35\text{ dm}^3$ .

As companies who build these fuel cells design them for the specific automotive field, there are still no fuel cells fitting the exact characteristics of Oiseau.

Arthur D. Little says, "The opportunities for further improvements in PEM fuel cell technology are impressive, further emphasizing the potential role of the technology as a major worldwide standard beyond 2000." <sup>18</sup> Fuel cells can promote energy diversity and transition to renewable energy sources. Hydrogen-the most abundant element on Earth- can be used directly.

Carbon nanotubes are a new method for the storage of hydrogen. One way carbon can arrange itself is in a sheet pattern like a honeycomb. This is the graphite form of carbon. The sheets are not bound tightly together, but if they are wrapped on top of each other, a very strong carbon nanotube is formed. Terry Baker, professor of chemistry at Northeastern University discovered carbon nanotubes, while he was doing research at the Atomic Energy Authority in Harwell, England. The carbon was a waste product of catalytic reactions. As a catalytic reaction proceeds, platelets of precipitated carbon stack below and above the metal particle. Different metals of course, produce different configurations of the platelets. The carbon may stack like crackers, some may stack slanted end to end resembling a herringbone, and some may stack in a bent formation creating tubes. A consistent property of the nanofibers is that the distance between each platelet is identical. The fibers are generally 5-100 micrometers in length and have a diameter of 5-100 nanometers, hence the name carbon nanotube. It has also been discovered that treating the nanotubes with nitric acid will open the caps on the end of the tubes. The interesting part concerning these carbon nanotubes is that their widths are just large enough for hydrogen molecules but too small for larger molecules. A typical hydrogen molecule consists of two hydrogen atoms. The hydrogen atom has the second smallest radius of all elements because its one electron is in the first orbital, which is the closest orbital to the positively charged nucleus. So the one electron is held very tightly to the nucleus thus decreasing the atomic radius. It is possible then that perhaps hydrogen can be stored in these carbon nanotubes.

Terry Baker realized the possibility of storage in carbon nanotubes. His research findings have produced astounding results they have been able to store 30 liters of hydrogen in one gram of carbon! This corresponds to approximately 75% hydrogen storage by weight. At this rate a 25-liter tank that is half the size of a gasoline tank and weighs 87-kg can power a car for 5,000 miles. These experiments have been repeated fifty times by Baker.

The following general process is followed to allow hydrogen to be stored in the carbon: The nanotubes are first washed in acid to remove any metal impurities, they are then heated to 900 degrees C and put under a vacuum to remove any gases that may be slits on the nanofibers. Hydrogen is then pumped into the system at a pressure of 120 atm. The hydrogen can then be released by gradually reducing the pressure. Note a pressure of 40 atm must be applied to keep the hydrogen in place. The pressure where the hydrogen gas will cease to be released from the carbon tubes has also yet to be determined. <sup>17</sup>

Assumption: considering that a 25-liter tank which is half the size of a gasoline tank and weighs 87 kg can power a car for 5,000 miles, and that an electrical engine of such a car required 33 kW (Toyota's Prius). Oiseau needs the same power but the mission requires it only to be able to do 36 miles (75 km).

Fuel cells produce electricity. This is not the desired form of energy for transportation. The electricity must be converted into mechanical power using an electric motor. The power required

at the output of the motor for the flapping wings is 32.2 hp. The engine is designed by the company Baldor.<sup>19</sup>

This motor weighs 60 kg (132.3 lbs.), but we can expect the within 20 years the electrical motor's weight will be reduced by 10 to 20%<sup>20</sup>, so we based our calculation of weight on the value of 112 lbs. The output of the motor is a rotation speed on a shaft; we need to convert this motion into an up and down motion, so that our wings will flap. Figure 9 is not at scale, but shows the principle of our transmission system.

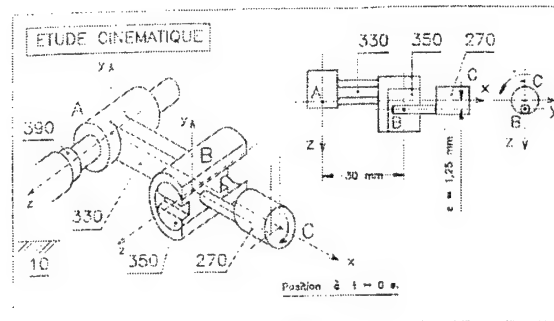


Figure 9. Principle of Transmission

### 5.3 Team 3 Solution – The Patrocinator

The Patrocinator has been created to meet all of the requirements set forth in the specifications from AMCOM. The Patrocinator is shown in

Figure 10. Patrocinator will get you there, will let you know what is out there, and will return safely faster, cheaper, and with higher performance than its competitors. This UAGV uses a completely silent ionic propulsion system that is powered by the next generation of fuel cells. It incorporates the use of an exoskeleton framework structure for a reduction in weight as well as for improved survivability. Sensors are imbedded into the skin to minimize housing components. The skin itself is comprised of layers of radar reducing material alongside high strength materials. The UAGV has good ground mobility and excellent communication with home base. Uniquely setting it apart from its competitors, the Patrocinator has a “top down” thinking process utilizing the best compilation of information gathering available. It's obvious, the Patrocinator delivers. Yes, it challenges its design team to package this cutting-edge vehicle for reliability but the system uses technology that is already out there in some form thereby minimizing overall costs for development.

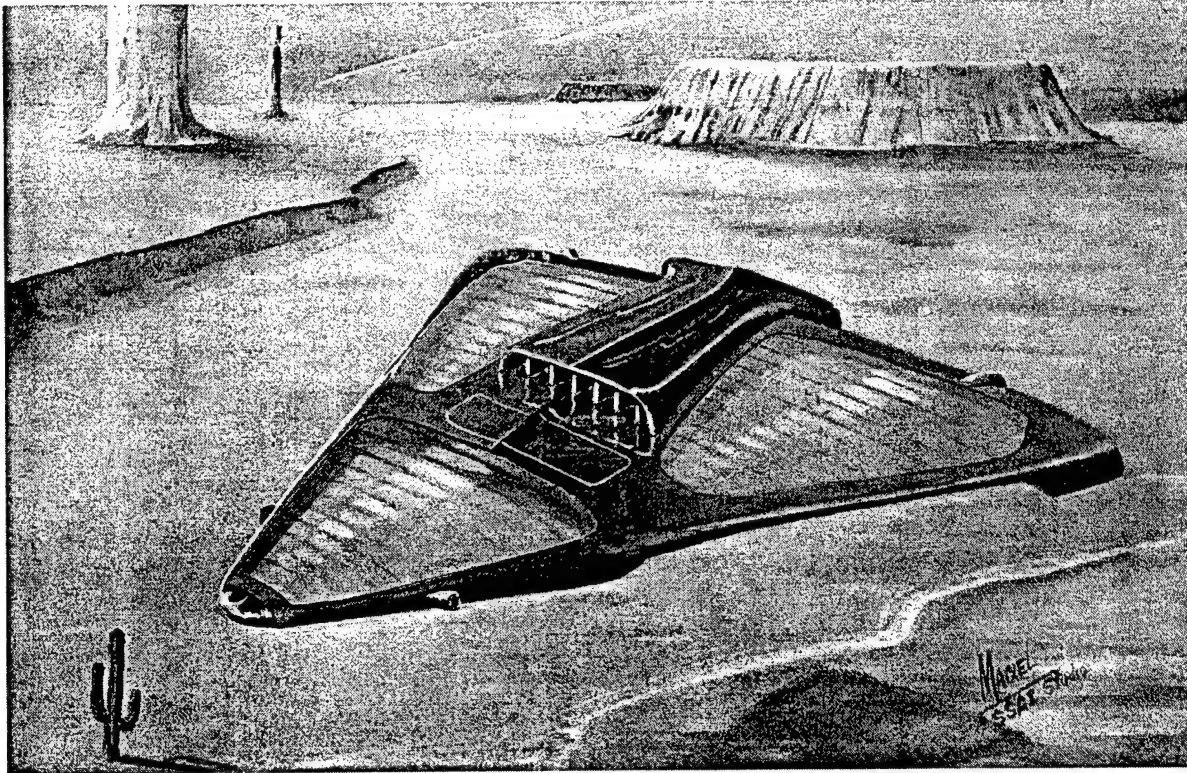


Figure 10. Team 3 Solution - The Patrocinator

Money is a good place to start in describing the key features of the Patrocinator. For an estimated cost of 170 mil in today's U.S. dollars the U.S. Army can have all of their needed capability by the year 2020. It's not the cheapest on the market but it is far from the most expensive. What AMCOM gets for its money is a vehicle that will change the face of warfare forever. Our soldiers will be protected well behind the front line while a swarm of Patrocinors communicate vital information about the enemy in real time back to home base. This comes at a fraction of the cost of some of the military's other high-tech ventures.

The Patrocinator brings to life ionic propulsion. This unique propulsion system has never been used in a military application before, but this system has no moving parts, no emissions, and minimal power requirements. Screens are used to charge air particles in the ducts and accelerate them out the back of the vehicle, in turn propelling the Patrocinator quietly and effectively to its destination.

Fuel cells are the propulsion method of choice for the Patrocinator. The decision to use fuel cells came about from the power to weight ratios that burdened the baseline design. Ultimately, fuel cells are being heavily researched at this time both by the military and commercial venues and they offer the best power in the smallest sizes and the cheapest costs.

Top down thinking is the only way to go. It is a feature that doesn't increase costs or complication. It is a methodology that raises reliability immeasurably and lends itself to the thought processes of the military operators who will be handling the Patrocinator. This thought process is unique to the Patrocinator, and developed solely by GRAD Inc. for the purpose of this

unmanned vehicle. The processes are based on requirements set forth in the specification. The advantages that Patrocinator brings to the table continue with the choice of materials for fabrication, aerodynamic design, and ground mobility.

The concept of ionizing air to produce a flow has existed since the 1950's. This technology is used in electro-static air cleaners. A high voltage potential is placed across two grids; the voltage potential ionizes the surrounding air and causes it to flow through the grids. The second grid is the collecting grid. The system easily removes significant amounts of airborne microscopic debris, thus providing cleaner air. Alexander P. de Seversky patented an electro-static system for propulsion in 1964. Seversky created a large, lightweight structure applying the above technology. He proved that enough lifting force could be produced to sustain flight of a heavier than air vehicle using a tethered power supply.<sup>21</sup>

GRAD Inc. chose ionic propulsion because of its quiet operation and low power consumption. The electro-static system produces no sounds except for the flowing air. This quality provides the vehicle with a lower chance of detection by enemy due to noise. In an article written about Seversky's invention the author claimed, "It sat there silently in midair."<sup>22</sup> Also, the system requires relatively low power use. This system when compared to a conventional rotorcraft design uses half the power to provide the same lift. Another benefit of the system is that it is less susceptible to damage from projectiles than a turbine or ducted fan. If a bullet is shot through the grids only a few wires may be damaged, but the remaining wires can still operate the vehicle.

The ionic propulsion system consists of a high voltage pulse generator connected to two grids or arrays of wires. A short distance of about four to six inches separates the grids. The top array has an emitting area approximately twenty times smaller than the receiving array. The voltage generator sends a varying positive charge to the top grid, while the bottom grid receives an equal negative charge. This voltage potential ranges from 50kV to 150kV. The surrounding air is ionized and pushed through the duct encircling the arrays. The force exiting the engines is adjusted by varying the voltage potential across the grids; the higher voltage produces more thrust. This allows the vehicle to lift from the ground, to a hover profile, and to a full flight profile. The source for horizontal thrust will be a smaller version of the engine mounted vertically. This engine will duct the airflow similar to a turbojet engine to add additional power.

Preliminary calculations have determined that the power required for the ionic engines is only 25kW. This is powerful enough to allow a VROC of 250 feet per minute. The horizontal engine will give a speed of 50 kilometers per hour.

Although this technology is not widely known, the ionic propulsion system is an easily constructed system. There is little maintenance needed; the system does not have any moving parts to wear out or breakdown. With little investment in development of the engines, there is the possibility of revolutionizing the propulsion industry.

## **6.0 THE SELECTED CONCEPT**

### ***6.1 Review Team Selection***

Table 3 summarizes the key technical characteristics presented by each of the teams. It also shows the key enabling technologies that will need investment to realize the implementation of the concept.

An Industrial Review Team selected the concept of Teams 2 as the best overall design. The reviewers made their evaluations based on a 50-page report and an oral presentation by each team. The used evaluation criteria based on the AIAA Design Competition that had been modified for this specific contest. The evaluation criteria included: technical content, organization/presentation, originality, and feasibility. The evaluation sheets re shown in Appendix C. Since the specification allowed a deployment in the year 2025, the teams could project technologies in their presentations. Details of the Review Team assessment are in Appendix D.

The Review Team liked the use of the Wankel engine to provide power for both the air and ground mode on the Team 1 design. The technology projections were clearly presented and the report was presented in a logical sequence. Challenges in driving the ducted fan and the wheels with the same RPM engine were noted along with the acoustic signature of the pulse-detonation engine.

The Review Team liked the bold, imaginative approach of Team 2. They thought their report was concise and well written. The concept also maximized the use of available development time to achieve the technology advances. They liked the electronic drive and the operations scenarios given. Challenges in mitigating the technical risk and the stability of the platform were concerns.

Table 3. Team Comparisons

Comparison Criteria	Team 1 Concept	Team 2 Concept	Team 3 Concept
Air Configuration	Ducted Fans, Wings	Flapping Wings	Ionic Propulsion
Ground Configuration	Semi-spherical Wheels on movable struts	Matracks	Ionic Propulsion, Landing Struts
Payload Mass, kg (lb)	(27.2) 60	68 lb	60 lb
Gross Takeoff Weight. kg (lb)	(218) 480	332 lb	300 lb
Energy Source for Air Transport	Wankel Engine (hover), PDE (Forward Flight)	Fuel cells	PEM Fuel cell
Energy Source for Ground Transport	Wankel Engine	Fuel cells	PEM Fuel cell
Hovering Power, kW (hp)	83.5(112)	35 kW(47 hp)	22 kW(30 hp)
Cruise Power at 15 km/hr , kW, (hp)	74.5 (100)	7.4 kW	23.8 kW
Total Energy for Mission Profile, KJ (BTU)	$1.079 \times 10^6$ ( $1.023 \times 10^6$ )	299,259 kJ (283,631 BTU)	$2.564 \times 10^5$ kJ ( $2.43 \times 10^5$ ) BTU
Basis of Autonomy	Computer	MACC	Thinking process
Primary BLOS Method	HF band	"Spy Oiseau"	Ultra-Wide Band
Primary Structural Material	Titanium, ABS plastic	Magnesium and Carbon Fiber	Carbon Fiber
Enabling Technology 1	PDE using heavy fuels	Fuel Cells and Electric Motors	Ionic Propulsion
Enabling Technology 2	Muffler Technology for PDE	Piezoelectric Material	Fuel Cells
Enabling Technology 3		Wing Material	Ultra-Wide Band
Enabling Technology 4		Chip on Flex Sensors	Vehicle Skin
Structure	Titanium	Magnesium Alloy and Carbon Fiber	Carbon Fiber
Fuel Weight		1.6 lbs	
Range		75 km	30 km

The Review Team thought that Team 3 had a novel approach to the customer requirements. The concept had a good mix of the state of the art with reasonable expectations for future technology development. The presentation of the material did not make clear the state of the art in ion propulsion and did not have a cohesive style. The use of ion propulsion for the ground mobility

fulfilled the basic operational requirements. A post-class literature review and experimental investigation of the ion propulsion concept is presented in Appendix E.

Using the evaluation criteria, the Review Team named Team 2's proposal for the Oiseau as the top concept. The teams were all commended for their novel ideas and broad look at possibilities for fulfilling the project requirements.

## 6.2 Oiseau Summary

Figure 11 shows the features of the Team 2 Oiseau. The vehicle is 16 feet wide and 5 feet long. It is constructed of a lightweight Magnesium alloy frame. The modular body and wing system allows easy detachment and access to the interior of the craft. The lift and air propulsion are provided by four flapping wings whose shape is controlled with piezoelectric wing warping. The power source is a high-efficiency fuel cell that drives electric motors for the wings and the ground tracks. The vehicle also has active camouflage that can assume any color based on the surrounding terrain.

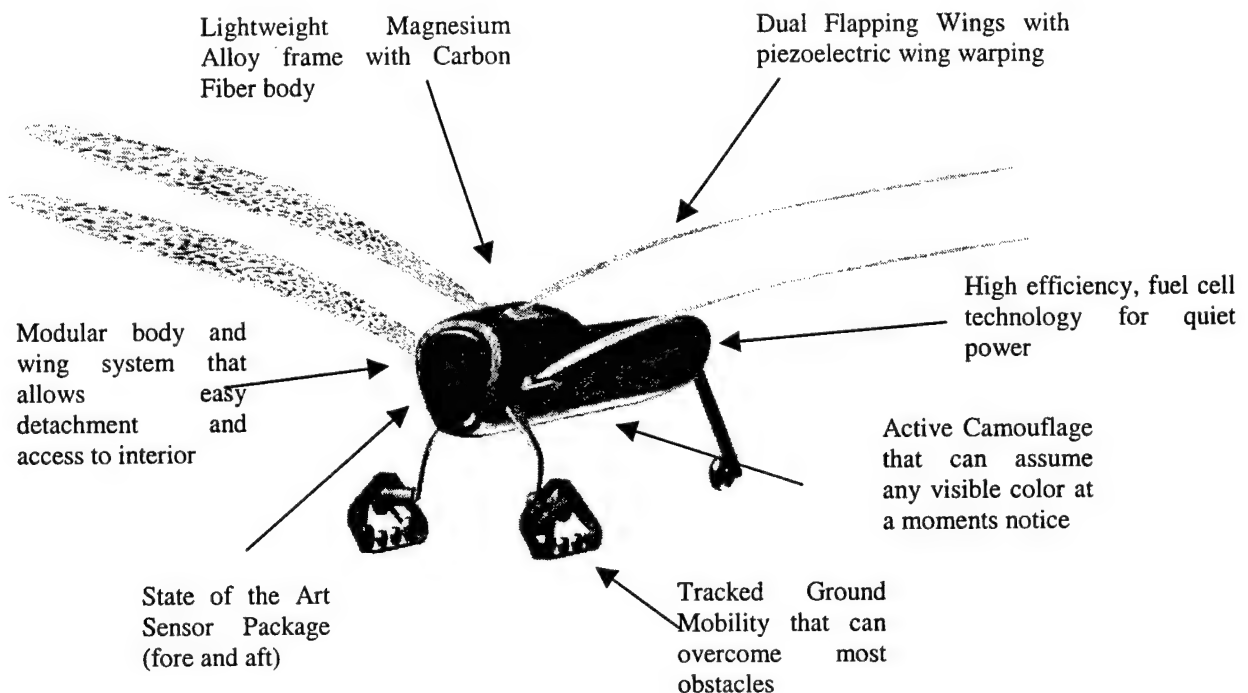


Figure 11. Key Features of the Oiseau

The assumed mission profile is for the vehicle to takeoff vertically close to the FLOT, climb at 250 fpm to a maximum altitude of 500 ft AGL (at high hot conditions), and cruise at 30 km/hr for 30 minutes (15 km range). The vehicle will then either hover for 60 minutes or land, traverse the ground and takeoff again and then fly back to the departure point. The sensor package and payload capacity will give the Oiseau considerable flexibility in terms of the operations it can perform.

Table 4 summarizes the estimated performance of the Oiseau in reference to the major aspects of the Concept Description Document. The vehicle meets or exceeds all the major requirement of the CDD. This of course is dependent upon critical technology development in the next few years.

Table 4. Selected Concept Evaluation

CDD Requirement	Requirement	Assessment
Range from launch point	15 km	30 km
Cruise Speed	30 km/hr	40km/hr
VROC	250 ft/min	360 ft/min
VTOL Capability	Yes	Yes
Payload:	60 lb	68 lb
Operational Altitude	0 to 500 ft AGL	0 to 500 ft AGL
Hover to full flight profile	Yes	Yes
Operation	Autonomous or Semi-autonomous	Autonomous or Semi-autonomous
Acoustic Signature	Near Quiet	Moderate to Near Quiet
Communications	BLOS	BLOS
Deployment	2025	2025

### 6.3 Implementation

There are several technologies whose further development is critical to the development of the Oiseau. One such technology is lightweight fuel cells and electrical motors. Fuel cells have been used for quite some time in spacecraft for the generation of electrical power; however, some adaptations are needed for the Oiseau. Although operating characteristics of electric motors are widely understood, a specific motor will have to be developed that is optimized for flight (i.e. high power to weight ratio, etc.). Another technology currently under development is Integrated Vehicle Health Management (IVHM). This is a computer software system that records: fault messages with Line Replaceable Units (LRUs) isolation, parametric and performance data, and warnings, cautions, and advisories.<sup>23</sup> This system can be used not only to schedule preventative maintenance, but to optimize sub-system performance as well. Another technology required is piezoelectric materials to be used by the control system. These materials, also currently under development, distort their shape when voltage is applied to them. Such devices will be built into the flexible wings. This will yield control over camber for aerodynamic effects and wing warping for controls.

Further technological development required includes wing material and lighter structural materials. The requirements for the wing material are unique. Directional gas permeability is required for aerodynamic reasons. There exist fabrics capable of such characteristics; however, better performance is, of course, needed. Lighter materials in general could greatly effect the performance characteristics of the Oiseau. Current research in this topic is broad and the shows much potential.

The next area of study needed is the development of software that can handle the autonomous operation of a UAGV. There is considerable development of software in the commercial arena.

Advance avionics packages should be developed to control the vehicle as it flies as well as coordinate the ground robotics.

There are considerable advantages to using flapping wing flight. However, there is considerable research work needed to fully implement the design. With an anticipated deployment date of 2025, there is ample time to complete supporting research. With this intended deployment date, detailed design will need to occur by 2016. The technology must then be available by this date to fulfill the specification. More specifically, the electrical propulsion system's research should be completed in the next 10 years (by 2011). The research for the wing material must be done in the next 12 years as well to allow for testing before detailed design begins. The software should be developed by 2011 as well and tested in an existing vehicle before 2014. The avionics should be developed in parallel with the software. The combination of the software and avionics should be tested before 2016.

### **ACKNOWLEDGEMENTS**

The project was supported with a grant from the U.S. Army Aviation and Missile Command. The contract managers were John Fulda and James Winkeler. Sverdrup Technology provided support for an Open House Event. The Redstone Chapter of the American Helicopter Society sponsored an awards luncheon (Photos in Appendix E) to recognize the students. The UAH Student Government Association provided money for student travel. Marie-Sophie Pawlak at ESTACA provided financial support for travel of ESTACA Students.

This project involved forty-four students from UAH and ESTACA who worked on the integrated product Teams including: Akmal Abdulakhatov, Cyril Augier, Jason Back, Majed Batais, Ben Bramblett, Segolene Branstchen, Kevin Buch, Jean-Emmanuel Bzdrega, Joe Caldwell, Shane Canerday, Younes Elkacimi, Laura Filz (Team 1 Leader), Julien Geffard, Brian Griffin, Timur Hakimov, Timothy Hardin, Matthew Harris, Damon Hay, Chris Hirstein, Francois-Xavier Hussenet, Pierrot Ivoula, Melanie Janetka (Team 2 Leader), Jon Kilpatrick, James Kodrowski, Sebastian Kriner, Kannathas Krishnassamy, Shane Lackey, Sheree Long, Kristopher McDougal, Jason Newton, Angeline Nuar, Demetrius Peoples, Rajat Sharma, Nathan Smith (Team 3 Leader), Richie Sparkman, Linda Taylor, William Thomas, Cedric Trophardy, Cederic VanEssen, Nicholas Vergenealt, Pascal Vidal, Timothy Weaver, Virgil White, Khalid Zarouni.

AMCOM personnel participated as mentors giving brief lectures to the class and serving as consultants throughout the project. They were John Berry, John Carter, Jim Dingess, John Fulda (Lead), Jim Kirkwood, Pat McInnis, Alfred Reed, Jim Winkeler (Co-Lead), and Virginia Young.

Mentors from other companies include: Sherry Adlich (Teledyne Brown Engineering), Phillip Farrington (UAH-ISE Dept.), Kader Frendi (UAH-MAE Dept.), Alex Maciel (SSAI Sigma Services of America, Inc.), John Piccarillo (UAH-ECE Dept.), Jim Sanders (UAH Propulsion Research Center), George R. Smith (Smith Enterprises).

The Design Review Team consisted of Industry Experts as follows: Lawrence Bavis (CAS Inc.), Dr. Henry L. Pugh (The Boeing Company), Dr. M. Frank Rose (NASA MSFC), Mr. Jan VanAken (NASA Ames), Mr. David Weller (AMCOM AMRDEC – Lead), and Dr. Virginia Young (AMCOM).

The following people served active support roles in developing Internet communications and administrative support for the class:, Alex Maciel Bob Middleton, Ina Ryzhkova, Ilya Shkolnikov, James Williamson, Beth Floyd, Brandy Carder, Suzi Bonn, and Sarah Paul.

The following faculty lead classes that were integrated together for this project Dave Berkowitz - Administrative Sciences; Paul Componation - Industrial and Systems Engineering; Charles D. Corsetti - Electrical and Computer Engineering; Robert Frederick – Lead, Mechanical and Aerospace Engineering; Rose Norman - English; Marie-Sophie Pawlak - ESTACA International Director; Dawn Utley - Industrial and Systems Engineering; and Earl Wells - Electrical and Computer Engineering.

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## APPENDIX A – CONCEPT DESCRIPTION DOCUMENT

The undersigned agree that the attached Concept Description Document as marked will be the basis the UAH IPT 2001 Design Competition. From this time forward, any questions or clarifications concerning the concept description document to the Customer shall be submitted in writing and the answer distributed to all UAH IPT's in writing.

To change the Concept Description Document Prior to April 30, 2001 shall require that the change be stated in writing and that a person authorized by every one of the signers below endorse the change with their signature. The revision will be labeled uniquely and distributed to all teams simultaneously.

The original of this document will be kept on file with the UAH Project Director. All signers will receive a copy of the original document.

\_\_\_\_\_/\_\_\_\_\_  
John Fulda, Customer

\_\_\_\_\_/\_\_\_\_\_  
James Winkeler, Customer

\_\_\_\_\_/\_\_\_\_\_  
Laura Filz, UAH IPT 01

\_\_\_\_\_/\_\_\_\_\_  
Melanie Janetka, UAH IPT 02

\_\_\_\_\_/\_\_\_\_\_  
Nathan Smith, UAH IPT 03

\_\_\_\_\_/\_\_\_\_\_  
Robert A. Frederick, Jr., UAH IPT2001 Project Director

# Concept Description Document

for  
Integrated Unmanned Air/Ground Vehicle

## 1. General Description of Operational Capability

### 1.1. Overall Mission Area



- 1.1.1. The system shall be a versatile scout and pack animal for future force structures.
- 1.1.2. The system shall be capable for use for area/target reconnoitering.
- 1.1.3. The system shall be capable for use in terrain definition.
- 1.1.4. The system shall be capable for use in situational awareness.
- 1.1.5. The system shall be capable of both autonomous and semi-autonomous operation.
  - 1.1.5.1. The system shall be capable of human interface as required.
- 1.1.6. The system shall be capable of executing both a preplanned and an alter mission profile.
- 1.1.7. The system shall be capable of navigating and functioning without a payload.

### 1.2. Operational Concept

- 1.2.1. The system shall be capable of operation in a nap of the earth configuration.
- 1.2.2. The system shall be capable of operation at a range of 15-30 km from the launch point.
  - 1.2.2.1. The system shall be capable of gathering information on threat activities at range.
  - 1.2.2.2. The system shall be capable of enhancing the RSTA/BDA.
  - 1.2.2.3. The system shall be capable of transmitting information via secure data links and C2 structures BLOS.
  - 1.2.2.4. The system shall be capable of using TF/TA hardware and software to define and navigate complex terrain.
  - 1.2.2.5. The system may encompass a degree of AI, ATR, and on-board decision making.
- 1.2.3. Payload Requirements
  - 1.2.3.1. The system shall be capable of carrying a payload of 60lbs required gross weight, 120lbs desired gross weight.
  - 1.2.3.2. The system shall be capable of moving the payload to operational range in 30 minutes or less and be able to return from range in 30 minutes or less.
    - 1.2.3.2.1. The vehicle will have a minimum cruise speed of 30 km/hr and a desired speed of 100 km/hr.
- 1.2.4. Mission Requirements
  - 1.2.4.1. The system shall be capable of landing in an unprepared area
    - 1.2.4.1.1. The vehicle must have vertical takeoff and landing capabilities.
  - 1.2.4.3. The system shall maximize survivability.
    - 1.2.4.3.1. The system shall be capable of avoiding sonic detection.
    - 1.2.4.3.2. The system shall have a near quiet acoustic signature.
    - 1.2.4.3.3. The system shall be designed for an operational altitude of 0 – 500 ft AGL.

- 1.2.4.3.4. The system must have a 250 fpm VROC, 500 fpm desired.
- 1.2.4.4. The system must have a flight profile of hover to full flight.
- 2. System Capabilities
  - 2.1. The system shall be capable of operation at an altitude of 4000ft, 95 degrees Fahrenheit ambient temperature, and not using more than 95% intermediate rated power (IRP).
  - 2.2. Operational Performance
    - 2.2.1. The system shall possess essential performance, maintenance, and physical characteristics required to operate under adverse environmental conditions worldwide.
    - 2.2.2 The system shall possess essential performance, maintenance, and physical characteristics required to operate under adverse geographical conditions worldwide.
    - 2.2.3. The system shall be capable of operating from any unimproved land or sea borne facility surface day or night, including low illumination.
    - 2.2.4. The system shall be capable of operation under battlefield obscurants.
  - 2.3. The system shall possess the following electronic capabilities:
    - 2.3.1. Mission Planning System
      - 2.3.1.1. The system shall possess a point-and-click pre-mission planning system to simulate mission flight.
      - 2.3.1.2. The system shall possess data loading capabilities.
      - 2.3.1.3. The system shall be capable of coordination and reaction to immediate operational mission changes.
      - 2.3.1.4. The system shall be capable of processing self awareness and threat sensor inputs.
      - 2.3.1.5. The system shall be capable of enabling TF/TA from digital mapping information from satellite or other sources.
    - 2.3.2. Avionics
      - 2.3.2.1. Communications and navigation suite architecture shall be compatible with emerging JCDL and/or JAUGS.
      - 2.3.2.2. Payload must be "plug and play."
    - 2.3.3. Communications
      - 2.3.3.1. System communications shall be robust and have clear secure modes of operation
      - 2.3.3.2. Communications shall be simultaneously LOS and BLOS which can include satellite relay or other relay system compatibility.
      - 2.3.3.3. System must possess IFF and be compliant to all FCC/military communication regulations.
      - 2.3.3.4. System must be capable of communication with and sharing digital mapping/targeting information with other DoD RSTA platforms.
    - 2.3.4. Connectivity
      - 2.3.4.1. The system shall be interoperable with other DoD systems envisioned for the 2025 battlefield to the maximum extent possible and be compatible with service unique C41 systems.




## APPENDIX B –BASELINE REVIEW CHARTS






# BASELINE REVIEW

## PAWNEE

IPT 2001  
The University of Alabama in Huntsville  
<http://www.cb.uah.edu/ipt2001>






# Project Requirements






# Overview

- Introduction
- Project Requirements
- Assessment of Current Technology
- Baseline Design Concept
- Recommendations
- Conclusions




# Necessity for Hybrid Vehicle

- Currently, UAVs and UGVs do not share information
- UAVs have vertical perspective of battlefield only
- UGVs need line-of-sight C2 and have limited ATR capability



# Introduction

- U.S. Army Aviation and Missile Command (AMCOM)
- Hybrid UAV/UGV
  - primary function is reconnaissance
  - implement at battalion level
- Requirements established to meet needs of future Army forces
- Anticipated deployment date of 2025



# Future Force Imperatives

- Increased Op Tempo
- More reliance on light and medium forces
- Reconnaissance forces that are capable of covering much more territory
- Reliance on robotics to for “dirty, dangerous, and dull” missions
- “Clean” war for American troops (the CNN factor)



ESTACA 2007-2008

## Concept Description Document

- Alpha Contract
- Content
  - Operational Concept
  - Payload and Mission
  - System Capabilities
- Finalized after Phase I

UAH

ESTACA 2007-2008

## Initial Assessment

- Research Existing Technologies
  - UAV Systems
  - UGV Systems
- Evaluation Based on Customer Requirements

UAH

ESTACA 2007-2008

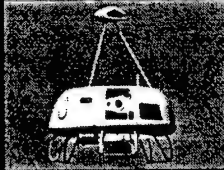
## Primary Requirements

- Range
  - 15 to 30km from launch point
- Cruise Speed of 30 to 100 km/hr
- VROC of 250 to 500 ft/min
- VTOL Capability
- Payload
  - 60 to 120 lbs
- Operational Altitude of 0 to 500 ft AGL
- Hover to full flight profile
- Semi-autonomous
- Near Quiet Acoustic Signature
- BLOS communications

UAH

ESTACA 2007-2008

## Sikorsky Cypher



- Strengths
  - Weight 300 lbs
  - Altitude 5,000 ft
  - Range 29 km
  - Endurance 2.5 hrs
  - Cruise Speed 129 km/h
  - Payload Weight 45 lbs
- Weaknesses
  - Adaptability to ground mobility

UAH

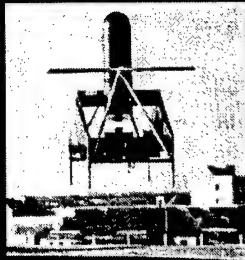
ESTACA 2007-2008

## Assessment of Current Technology

UAH

ESTACA 2007-2008

## Seabat



- Strengths
  - Altitude 10000ft
  - Endurance 3hrs
  - Cruise Speed 180kts
  - Range 184 km
- Weaknesses
  - Payload 50lbs
  - Ground Mobility

UAH

## MDARS

Mobile Detection Assessment and Response

- Strengths
  - Highly Mobile Package
  - Adaptable
  - Semi-Autonomous
  - Utilizes Mapping and Detection Equipment
- Weaknesses
  - Currently Does Not Utilize All RSTA Components Necessary
  - Not Fully Autonomous
  - Doesn't Fly

## Baseline Design

## SARGE

Surveillance And Reconnaissance Ground Equipment

- Strengths
  - Highly Mobile Package
  - Highly Adaptable
  - Payload Capability
- Weaknesses
  - Not Autonomous
  - Currently Does Not Carry All RSTA Components Necessary
  - Doesn't Fly

## Baseline Overview

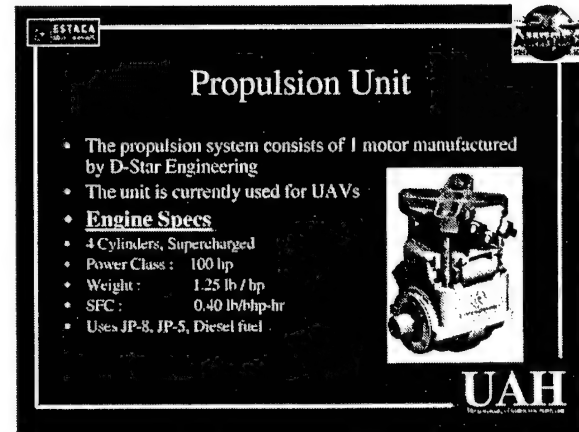
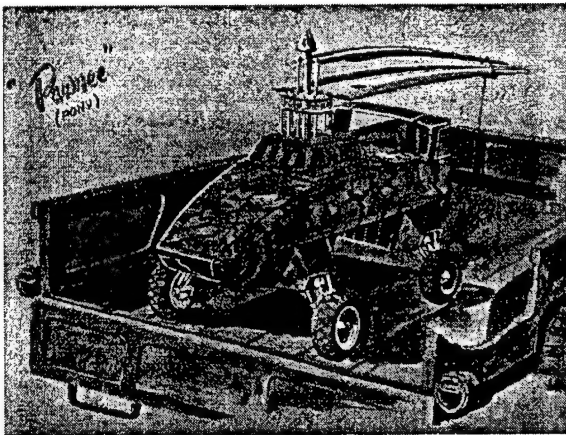
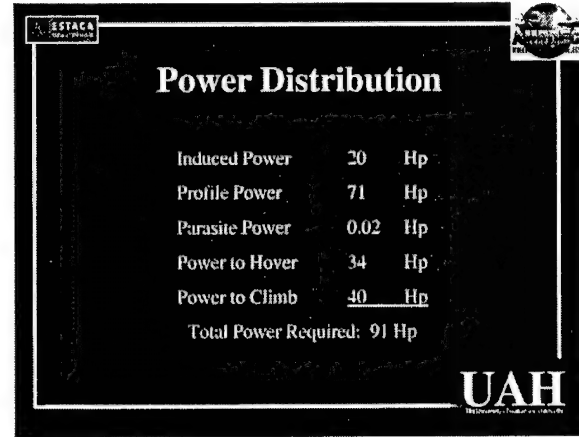
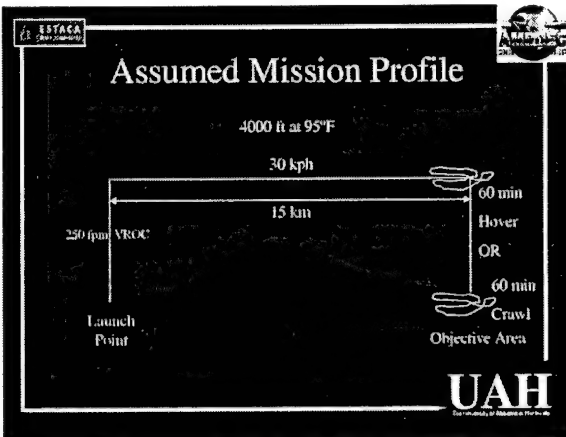
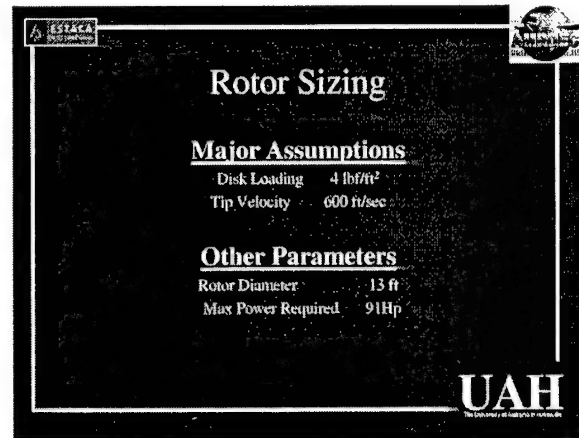
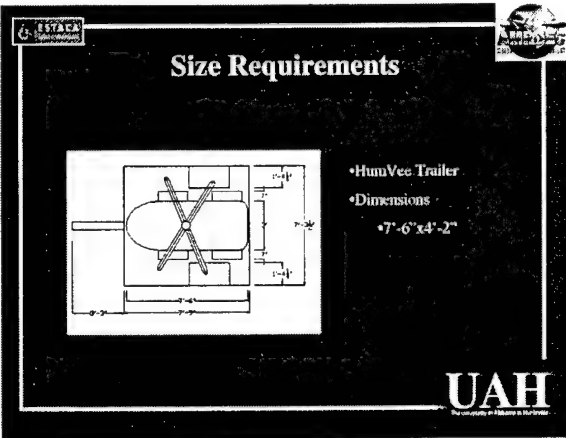
- Assumptions
  - Flight Profile
- Subsystem Configuration
- Summary of Baseline Design


## Performance Evaluation Matrix

	Cypher	Sea Bat	Sarge	MDARS
Range: 15 km from launch point	0	0	0	0
Cruise Speed of 30 km/hr	0	0	0	0
VROC of 250 ft/min	0	0	0	0
VTOL Capability	0	0	0	0
Payload: 60 lbs	0	0	0	0
Operational Altitude of 0 to 500 ft AGL	0	0	0	0
Hover to full flight profile	0	0	0	0
Autonomous or Semi-autonomous	0	0	0	0
Near Quiet Acoustic Signature	0	0	0	0
BLOS communications	0	0	0	0


## Baseline Assumptions

- 2001 Level of Technology
- Nominal Level of Compliance
- Rotorcraft Flight System
  - Counter rotating
- Target Weight = 600 lbs
- Wheel Driven
- Heavy Fuels



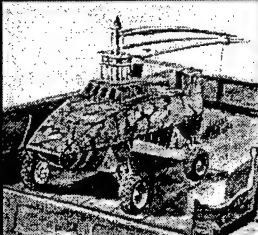



**ESTACA**  
European Association of  
Technical Universities



# Materials and Structures

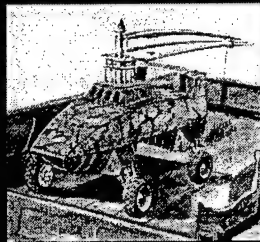
- Frame
  - Titanium
- Skin
  - Carbon Fiber
- Blades
- Tires
  - Rubber Wheels
  - Aluminum Rims
- Fuel Tanks
  - Carbon Fiber



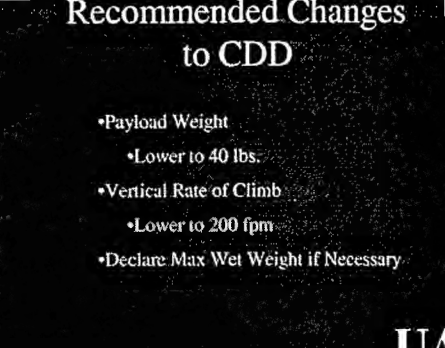


The University of Alabama in Huntsville

- Frame
  - Titanium
- Skin
  - Carbon Fiber
- Blades
- Tires
  - Rubber Wheels
  - Aluminum Rims
- Fuel Tanks
  - Carbon Fiber



# UAH



**ESTAGE**  
The University of Arizona

**ARIZONA**  
The University of Arizona


# Recommended Changes to CDD

- Payload Weight
  - Lower to 40 lbs.
- Vertical Rate of Climb
  - Lower to 200 fpm
- Declare Max Wet Weight if Necessary

**UAH**  
The University of Arizona

- Payload Weight
  - Lower to 40 lbs.
- Vertical Rate of Climb
  - Lower to 200 fpm
- Declare Max Wet Weight if Necessary

# UAH

<div> <div>ESTACA</div> <div>European Space Technology Association</div> </div> <div>  </div>	
<h1>Weight Summary</h1>	
• Propulsion	113
• Sensors/Communication	50
• Ground Robotics	106
• Frame/Armor skin	145
• Fuel	120
• Payload	60
• Miscellaneous	<u>20</u>
Total:	614
<div> <div>UAH</div> <div>The University of Alabama at Huntsville</div> </div>	

• Propulsion	113
• Sensors/Communication	50
• Ground Robotics	106
• Frame/Armor skin	145
• Fuel	120
• Payload	60
• Miscellaneous	<u>20</u>
Total:	614

# UAH

**ESTACA**  
European Association  
of Transport  
Acoustic Consultants

**Acoustic Analysis**  
1998

# Concluding Remarks

- Established Specification (CDD)
- Existing Systems Deficient
- Baseline Design
  - Shows Existing Technology Deficient
  - Vertical Rate of Climb
  - Acoustic Signature
  - Sensors and Controls
  - Autonomy
- Proceed to Phase II

**UAH**  
The University of Akron

- Established Specification (CDD)
- Existing Systems Deficient
- Baseline Design
  - Shows Existing Technology Deficient
  - Vertical Rate of Climb
  - Acoustic Signature
  - Sensors and Controls
  - Autonomy
- Proceed to Phase II

# UAH

# Sensors and Communications

- LIDAR
  - (Light Detection And Ranging)
- Primary C-Band
  - Directional
  - Omni-Directional
- Secondary L-Band
  - Omni-Directional
- Guidance
  - GPS & Inertial
- Map of the Earth Flight

# UAH

[illegible]

- [illegible]

# UAH

### APPENDIC C – EVALUATION CRITERIA/ JUDGING INSTRUCTIONS<sup>1</sup>

As a recognized authority in your technical specialty by the UAH IPT Review Team Chairman, it is your responsibility to conduct a careful and thorough judging of three proposals. To provide a broad, impartial judgment, at least two other independent reviews of this paper will be made. The judging criteria contained herein are intended as both a guide for the judges and as an evaluation sheet for the student's paper. The judges should already be familiar with the detailed requirements of the Concept Description Document (CDD), which is Attachment 1. It is left to the judge's discretion to deviate high or low from the suggested point distribution. Please be aware that any additional comments you may care to make about the contents of the paper will be beneficial to the students.

The judges should review and score the applicable categories on this sheet before the final oral presentation. At the oral presentation, each team will make a time-limited, uninterrupted presentation. The Review Team will then have a timed question and answer period. Following all the oral presentations, the Review Team Chairman will ask for discussion and scores from each member of the Review Team. If the Review Team Chairman feels that the results represent the majority opinion of the Review Team, the scores will be passed to the IPT2001 Project Director. At this point, any deductions related to late submission or other factors are applied and the final scores are adjusted. A summary sheet is Appendix B.

<b>PROPOSAL INFORMATION</b>	
<i>Project Name:</i> <u>Unmanned Air/Ground Vehicle</u>	
<i>Team No:</i> _____	
<i>Team Leader:</i> _____	

<b>COMPETITION INFORMATION</b> <i>Baseline Review: February 1, 2001</i> <i>Alternative Concepts review: March 1, 2001</i> <i>Submission of Final Proposal: April 23, 2001</i> <i>Final Oral Review: April 26, 2001; 3:00 – 6:00</i> <i>Awards Banquet: April 27, 2001; 11:00-1:00</i>	<b>SCORING Summary</b> Technical Content Final Grade _____ Organization/Presentation Final Grade _____ Originality _____ Application/Feasibility _____ <b>FINAL SCORE</b> _____
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REVIEW TEAM CHAIRMAN	IPT 2001 PROJECT DIRECTOR
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<sup>1</sup> Adapted from AIAA Design Competition Review Sheets

## REVIEW OF TECHNICAL CONTENT

Scale Factor = 0.35

1. Did the Team complete all of the requirements of the RFP? Yes\_\_\_ No\_\_\_
  - a) If total RFP requirements were not met, was an alternate solution(s) supplied? Yes\_\_\_ No\_\_\_
  - b) Was the reasoning used for alternate solution(s) valid? Yes\_\_\_ No\_\_\_
  - c) Was the theory of alternate solution(s) correct? Yes\_\_\_ No\_\_\_
  - d) Are benefits of alternate solution weighed against RFP requirements substantiated? Yes\_\_\_ No\_\_\_
2. Did the written technical presentation illustrate an overall understanding of the subject? Yes\_\_\_ No\_\_\_
3. Any additional comments regarding judge's score.


	Average	Maximum	Judges Score
1. Completion of RFP Requirements	14	20	*__
2. Determination of critical problems	7	10	*_
3. All major and related parameters considered	7	10	*
4. Well balanced analysis of complete system.	7	10	*
5. Assumptions clearly stated and logical	7	10	*
6. Reasonably accurate evaluation.	7	10	*
7. Validity of reasoning.	7	10	*
8. Correctness of theory	7	10	*
9. Direct relations of technical approach to RFP problems	3	5	*
10. Technical sketches relevant, necessary, complete	3	5	*

**\*TOTAL  
POINTS**  
\_\_\_\_/100

**Scale Factor x Total Points = TECHNICAL CONTENT FINAL GRADE**

**Technical  
Content  
Grade**  
\_\_\_\_/35

## ORGANIZATION AND PRESENTATION

Scale Factor = 0.20

It is suggested that the judges fill in Part I as a basis for an accurate point evaluation before filling in Part II.

### PART I - ADEQUATE BASIS FOR PRESENTATION

	YES	NO
1. Does paper avoid short, choppy sentences/paragraphs?	___	___
2. Is paper free from unnecessary footnotes?	___	___
3. Is paper free from numerous/unnecessary "bullet lists"?	___	___
4. Is paper free of excessive parenthetical comments?	___	___
5. Is paper of minimum feasible length?	___	___
6. Does paper contain unimportant details that could be deleted?	___	___
7. Are all mathematical symbols defined?	___	___
8. Are mathematical analyses/derivations clear?	___	___
9. Is each figure and table relevant?	___	___
10. Was the Oral Presentation clear concise and easy to understand?	___	___

### PART II - ORGANIZATION and PRESENTATION POINT EVALUATION

Score	Average	Maximum	Judges
1. Conclusions are concise and fully substantiated	10	15	* ___
2. Paper alerts reader to controversial material, major contributions, key results	7	10	* ___
3. Continuity of topics	7	10	* ___
4. Introduction clearly defines purpose of paper	. 7	10	* ___
5. All pertinent information included	. 7	10	* ___
6. Figures, graphs, tables are uncluttered and are easy to understand	7	10	* ___
7. All previous relevant work cited.	7	10	* ___
8. Overall neatness of report	. 7	10	* ___
9. Oral Presentation clear, concise, and credible	10	15	* ___

Total  
Score  
\_\_\_/100

**Scale Factor x Total Points = ORGANIZATION/PRESENTATION FINAL**

GRADE \_\_\_\_\_

Organization and  
Presentation Final  
Grade \_\_\_\_\_/20

**ORIGINALITY**  
**Factor = 0.20**

**Scale**

	<i>Average</i>	<i>Maximum</i>	<i>Judges Score</i>
1. Design concept shows originality	25	35	* <u>      </u>
2. Treatment of problem shows imagination	17	25	* <u>      </u>
3. Results illustrate a unique solution	14	20	* <u>      </u>
4. Appearance of report shows originality	14	20	* <u>      </u>

**\*TOTAL  
POINTS**  
      /100

***Scale Factor x Total Points = ORIGINALITY FINAL GRADE***       

**Originality  
Final Grade**  
      /20

Any additional comments regarding judge's score.

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**APPLICATION AND FEASIBILITY****Scale****Factor = 0.25**

<i>Score</i>	<i>Average</i>	<i>Maximum</i>	<i>Judges</i>
1. Consideration of simplicity in manufacturing	14	20	* <u>      </u>
2. Current and advanced technology levels are realistic	14	20	* <u>      </u>
3. Feasibility of meeting certification requirements	12	17	* <u>      </u>
4. Discussion of advantages and disadvantages of proposed design versus operational requirements.	10	14	* <u>      </u>
5. Consideration of additional applications other than solely meeting RFP....	10	14	* <u>      </u>
6. Environmental impact discussed and justified	3	5	* <u>      </u>
7. Social acceptance of solution	3	5	* <u>      </u>
8. Demonstration of cost effectiveness	3	5	* <u>      </u>

**\*TOTAL  
POINTS  
\_\_\_/100**

**Scale Factor x Total Points = APPLICATION/FEASIBILITY FINAL  
GRADE    \_\_\_**

**\*APPLICAT  
ION AND  
FEASIBILIT  
Y FINAL  
GRADE  
\_\_\_/25**

9. Any additional comments regarding judge's score.

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## FINAL REMARKS

Please use this section for any final or overall comments.

Overall Positives about the Proposal:
Overall Weaknesses of Proposal:

## **APPENDIX D – REVIEW TEAM FINAL SCORING**

### **TEAM 1**

CATEGORY	Pos	Rev. 1	Rev. 2	Rev. 3	Rev. 4	Rev. 6	
Technical Content	35	28	29		28	22	
Organization/ Presentation	20	15	18		18	13	
Originality	20	15	18		17	13	
Application/ Feasibility	25	19	21		22	15	
TOTAL	100	77	86		85	63	
AVERAGE							

### **TEAM 2**

CATEGORY	POS	Rev. 1	Rev. 2	Rev. 3	Rev. 4	Rev. 6	
Technical Content	35	32	35		28	22	
Organization/ Presentation	20	18	20		14	17	
Originality	20	19	20		19	17	
Application/ Feasibility	25	19	25		18	17	
TOTAL	100	88	100		79	73	
AVERAGE							

### **TEAM 3**

CATEGORY	Pos.	Rev. 1	Rev. 2	Rev. 3	Rev. 4	Rev. 6	
Technical Content	35	19	24		23	24	
Organization/ Presentation	20	13	18		13	15	
Originality	20	15	19		16	20	
Application/ Feasibility	25	16	22		19	19	
TOTAL	100	63	83		71	78	
AVERAGE							

	TEAM 1	TEAM 2	TEAM 3
FINAL AVERAGE			
DEDUCTIONS <sup>2</sup>			
FINAL AVERAGE			
FINAL RANKING			
MAJOR POSITIVES:			
MAJOR WEAKNESSES			

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<sup>2</sup> Proposal less that one hour late deduct 10 points, other deductions as applicable. IPT Project Director controls all deductions.

#### APPENDIX D – AHS BANQUET PHOTOS



IPT2001 Leadership. David Weller, Laura Filz, John Fulda, Melanie Janetka, General Sullivan, Nathan Smith, Robert Frederick, Jim Winkler, and Frances Johnson.



photo\_43.jpg